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THE

MOON'S ROTATION

EXAMINED BY

THE NEWTONIAN THEORY

OF GRAVITATION

BY

THOMAS F. TYERMAN.

OXFORD:
SLATTER AND ROSE, HIGH STREET.
1885.

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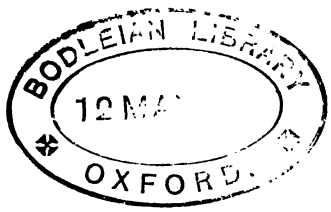

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THE MOON'S ROTATION.

It never happens that the man who makes a great discovery, lives long enough to learn every possible application, or every possible consequence, of the important discovery he has made. One life is too short, however laborious it may have been. There is comprehended, under every great law of nature, such a vast series of particulars, that the future has more fruit to bring forth than the broadest generalization of the facts already known, even if aided by a glowing imagination, can possibly suggest. Science cannot achieve all its ends *per saltum*, but must be content to advance by the slow accumulation of facts and evidences, with, now and then, a sudden start in advance. One man discovers one thing, and another, another, while a third man finds the application of what the other two have brought to light. If then a man has succeeded in making a great discovery, has set a noble example, and has pointed out the true path of investigation, it is all that can be expected of human nature, even in its exaltation.

Newton's life was sufficiently laborious, but with all his application he was obliged to leave a good deal of

unfinished work for his successors to take up. His thoughts were always practical; and in the endeavour to unite practice with sound theory, he felt that the real advancement of the natural sciences must depend upon the interpretation of nature, and a suitable application of the laws of nature to given examples.

He nobly led the way by the application of his own theory to the problem of the "moon's variation and "parallactic inequality"; but how great would his satisfaction have been had he lived long enough to know that all the difficult problems connected with planetary perturbation and compensation had been, one after another, solved by the proper application of his theory.

The problems of the "great inequality of Jupiter and "Saturn," and "the sæcular acceleration of the moon's "mean motion," were long before the world, and it was denied, over and over again, that these could be solved by any application of the theory of gravitation; but in the hands of Laplace they both yielded to that theory.

It would be a pleasing subject for contemplation, had Newton lived long enough to learn that the solar system, for the stability of which he trembled, had been shown to be, for ever, stable, and upon his own theory. Lagrange has demonstrated, in his three celebrated theorems, the entire stability of the system; his only postulate being that the force of gravitation should, for

ever, continue as at present, or that the members composing the solar system should always mutually gravitate as they do now. This being granted, he shows such a connexion between the masses, major axes, mean motions, and periodic times of the planets, that these must, for ever, continue to revolve about the sun in orbits of the same magnitude as those in which each of them now moves. In another theorem he shows the stability of the system as regards the inclination of the planes of the planetary orbits; and, in a third, its stability as regards the excentricities, although immense periods of time may be necessary for the compensations.

The difficulty arising out of the problem of the revolution of the lunar apsides, and the circulation of the apogee, which Newton did not succeed in clearing up, was, after repeated attempts, removed by the French astronomer, Clairaut, who showed the exact agreement between theory and observation, the demonstration being made on the Newtonian theory. It was by reliance on the theory of gravitation, that Bouvard, after satisfying himself that the perturbations of Uranus could not be due to the influence of Saturn or Jupiter, threw out the suggestion that these might be caused by some unknown force by which the planet was acted on, that is, by a mass of matter revolving in space many hundreds of millions of miles beyond the orbit of Uranus. Many years afterwards, the same thought having been suggested and acted upon, the hypothetical

planet was converted into a real one by the discovery of Neptune, the undisputed boundary-keeper of the planetary orbits.

A solar system may be described as a vast machine, constructed of widely separated parts or members, which parts, at the same time that they are allowed the utmost freedom of motion, within certain limits, are held together, with the greatest firmness, by the invisible and indissoluble bond of gravitation. In a system so constructed, we find the two great forces employed by nature, viz., motion and gravitation, in constant operation. The result is determined, not by magnitude, but by mass, or the quantity of ponderable matter contained by each body; for, upon this depends its gravitating force or energy. The sun has a twofold office to fulfil: 1. By his great and overpowering mass, to retain the planets in their orbits about himself. 2. To radiate light and heat, to be received by their surfaces as they move round him.

It might naturally enough be thought, at first, that the great object would be to bring all these globes as near as possible to the sun, whereas the inter-planetary spaces continue to get wider and wider almost to the last; this mode of distancing being without doubt very exactly designed, according to the force of gravitation; and so fertile is the invention of the Great Creator, that He finds no difficulty in adapting the several anatomical and physiological peculiarities of the various races

of animated beings which He has called into existence, to the climate and atmospheric constitution of the abodes appointed for them.

A centrally placed sun then, with all these world-dwellings revolving around him, and turning round on their axes, so that their surfaces might catch, one part after the other, his light and heat, is a conception of the most wonderful beauty.

Most of the planets have satellites, or moons, revolving around them, and the motions of these about their primaries are regulated by the same laws as those which determine the orbits of the planets about the sun; and while studying the several constituent parts of the system, it is impossible not to be struck by the sparing distribution of satellites to those planets which revolve in the immediate neighbourhood of the sun. Mercury has no moon, and Venus has no moon, the earth being the first planet, reckoning from the sun, which has a satellite. The conviction of exactness of plan is here actually forced upon us. Should Mercury, in his very excentric ellipse, at a distance of only thirty-six millions of miles from the sun, and moving at the rate of thirty miles every second, be made to carry the orbit of a moon, we should tremble for the safety of a satellite so circumstanced. But Venus has no moon; why should not Venus have a moon as well as the earth? would not a satellite be safe in her keeping?

Is the proper answer to the question then—why should not Mercury and Venus have moons?—Because, according to the established laws of gravitation, the operation of which, the Creator never interrupts, such moons would not be in safety? The earth is allowed one satellite: but so powerful is the gravitation of this to the sun, that if the sun's mass were only a little greater, or the moon a little farther from the earth, there would be danger of her being drawn off from her allegiance to her primary, and made to move round the sun in an orbit of her own. With such exactness then are the several masses composing the solar system, adapted to one another, in reference to the force of gravitation! As we get further from the sun, the satellites are more plentifully distributed; Mars has two, very minute, Jupiter four, Saturn eight, &c.

Since the discovery of Uranus and Neptune, we can better understand the reason why the sun's mass should so greatly preponderate over the united masses of all the planets and satellites, than when the orbit of Saturn was believed to be the boundary of our system. Uranus is as far from Saturn as Saturn is from the sun; and now we have to stretch out into space many hundreds of millions of miles beyond the orbit of Uranus, to reach that of Neptune; the sun's gravitating influence then has to extend over a much wider range than to the limit formerly assigned to it.

As our attention now is to be especially directed to

the two great forces of nature, motion and gravitation, it may be as well to say a few words concerning each of them. All natural motion is in a straight line; and, by a law of motion, when a body, having inertia, is impelled by a force in any direction, it will go forward in a straight line in that direction, and with the initial velocity, for ever, unless deflected by some attraction, and so made to move in a curved line. But, having been so deflected, it will continue to move in the curved line just as well as in the straight line; its velocity not being diminished by the gravitating force to which it is now subject.

Gravitation is that power by which particles of matter, or masses composed of such particles, are made to draw towards one another, the force being exactly in proportion to the quantity of ponderable matter contained by each mass, and varying inversely as the square of the distance by which the masses are separated from one another.

Gravitation then is that invisible, but amazing force, with which every particle in the universe was inseparably identified on the very birth of matter; and it is by the unerring operation of these two great forces that the planets have been determined in their orbits about the sun; and, at the same time, have been so restrained, that they can never transgress their prescribed boundaries; not being permitted to approach nearer to him, or to stray farther from him. We view them as they

silently move in their eternal rounds; obedient to the laws thus imposed upon them; and while with mingled feelings of awe and admiration, we witness, in full operation, these astonishing examples of invention and power, we are taught by them also to understand how it is that "He hath held them fast for ever and "ever, and hath made them a law which shall not be "broken."

We shall often have occasion to appeal to these two forces in the following pages, which are especially devoted to the satellite system, our own moon being the satellite chosen for observation and inquiry; not suffering ourselves to be detained by her interesting and variegated surface, by her black-and-white landscapes, by her long ranges of rocky mountains and deep, shadowy vales, by her jagged peaks and precipices, at the foot of which are spread vast plains, which look lustrous and vivid in the glaring sunshine, and are sharply neighboured by regions, dark and dusky, where dwell the impenetrable glooms, and by small enclosures fringed with ragged rocks, from which the eye is drawn to skirt profound abysses full of mystery, burnt-out volcanoes in pimpled patches and curved lines, then to rings of light which encircle the black throats of enormous craters—all of which the total absence of clouds permits us to discern so plainly, and makes us long for even one transient view of that other hemisphere which no mortal eye has ever seen or

ever will see; but proceeding, after giving a short description of her magnitude, relative weight, librations, and the form of her orbit, to the consideration of her compound motion in that orbit; that is, her motion of translation, and her motion of rotation.

The moon is distant from the earth, reckoning from centre to centre, two hundred and thirty-seven thousand miles, this being the mean distance; but reckoning from surface to surface, this distance has to be abated by one equatorial radius of the earth, and by one radius or semidiameter of the moon. Seen then from the earth's surface, the visual ray will traverse an interval of two hundred and thirty-two thousand miles. At this distance then, the moon describes an orbit round the earth in twenty-seven days seven hours forty-three minutes and a few seconds, the direction of her motion being from west to east. This orbit is not a circle but an ellipse, the earth's centre occupying its lower focus; the moon is therefore necessarily nearer to the earth at one time than at another; and she moves most rapidly when nearest to the earth, and least so when farthest from it. The linear extent of the orbit is one million four hundred and twenty-four thousand miles. The point of the moon's nearest approach to the earth is called the perigee, and that where it is most distant, the apogee; and an imaginary straight line, drawn from one of these points to the other, through the earth's centre, is the line of

apsides; which is also the major axis of the orbit. The laws of Kelper, which Newton has shown to be a neccssary consequence of gravitation, are equally applicable to the moon's orbit as to that of a planet. 1. If a straight line, connecting the earth's centre and that of the moon, be carried round with the moon in her orbit, it will pass over equal areas in equal times. 2. The moon's orbit is elliptic, the earth being situated in one focus of the ellipse. 3. The law which shows a proportion between the periodic times and the mean distances, is in operation here, and every variation of distance is accompanied by a variation of velocity. The moon has a diameter of two thousand one hundred and sixty miles, and a circumference of six thousand seven hundred and eighty-eight miles. The earth is very much larger than the moon; its equatorial diameter is seven thousand nine hundred and twenty-five miles, the polar being twenty-six miles less; the bulging matter of the equator which causes the earth to assume the form of an ellipsoid, is thirteen miles in depth all round the line of the equator, this being half the number of miles by which the equatorial exceeds the polar diameter. The magnitude of a spheroid being as the cubes of the equatorial radii, it follows that the earth is almost exactly fifty times larger than the moon; the earth then would divide into fifty moons, each having a full diameter of two thousand one hundred and sixty miles. But when we come to form an estimate of the

relative mass or weight of the two spheres, the figures will be found to stand very differently, the earth's mass being seventy-five times greater than that of the moon; that is, if the earth's mass were divided into seventy-five equal masses, the moon would exactly balance one of these masses.

If we compare the earth's bulk with that of the sun, proceeding again by the cubes of their radii, we find that the sun exceeds the earth, in magnitude, by nearly one million four hundred thousand times; but when we compare the earth's mass with that of the sun, we find it to be exceeded by the sun's weight or mass in the proportion of three hundred and fifty-five thousand to one; that is, it would require three hundred and fifty-five thousand earths to balance the sun; and as every one of these earths would require seventy-five moons to balance it, it follows that it would require considerably more than twenty-six millions and a half of moons to balance the sun, and to do what the sun does in respect of gravitation and keeping the planets in their orbits, if placed where the sun is situated.

The plane of the moon's motion is not coincident with that of the ecliptic, but is inclined to that plane by an angle of nearly five degrees and nine minutes. The moon rotates slowly on her axis, the plane of rotation being inclined to the ecliptic by an angle of one degree and thirty minutes. One part of the moon's surface then is continually moving towards the sun,

while another part is, as slowly, moving away from it, the sun being always vertical to some part of her surface. This rotation being completed in one month, the moon's seasons, if they really deserve that name, must be of very brief duration.

The moon makes one complete turn on her axis in exactly the same time that she describes one sidereal revolution in her orbit. In consequence of this coincidence in time of the two revolutions, we are acquainted with only one hemisphere of the moon.

When viewed from the earth's surface, the moon is always seen from some point of the circumference of a circle; and, being so near the earth, while her concave path so nearly coincides with the earth's convex outline, it follows, that any spot of the moon's disc, fixed upon soon after she has risen, will not appear exactly in the same place as she approaches the meridian; this apparent change arising from the several perspective views which we take of the hemisphere; in the first view the visual ray being nearly horizontal, while in the second, its direction is more nearly vertical.

In consequence of the moon's libration in latitude and longitude, a spot, which is exactly central to the disc, will appear to sway a little, first to the east and then to the west, and again at right angles to this line, as if the convex hemisphere would trace out a spherical cross; we consequently see a narrow strip all round the disc, of the more remote hemisphere.

The plane of the moon's motion is continually altering, and, at the same time, the axis of her ellipse is rapidly making a complete revolution, and in the same direction, as her motion.

The moon returns, to the higher limits of our atmosphere, the sun's white light; but the colourless ray, as it traverses its denser strata, becomes refracted, with the development of the primary colours, and their several combinations; the moon, in consequence, is beautifully tinted with various complexions of yellow and orange. Without this adventitious aid, the moon would exhibit no colour whatever: Saussure, being high up on Mont Blanc on the night of a full moon, states that her disc resembled a plate of burnished silver set in a ground of ebony.

The moon has caused a great deal of trouble to men of science; so much so that a late eminent astronomer has called her a "rebellious satellite"; our next neighbour, Venus, having no moon, her astronomers are exempt from this trouble; at the same time, however, they are deprived of a very important help towards acquiring a knowledge of the laws of motion and gravitation, and of advancing, step by step, to an acquaintance with the great scheme of creation.

After all this trouble then, it seems somewhat surprising that certain of the moon's peculiarities, such as her slow and languid style of turning herself round, and the curious coincidence in time of her motions of rota-

tion and revolution, have not fairly exhausted the patience of astronomers.

There is still, therefore, a little difficulty about the moon. It is still thought that the coincidence referred to, is nothing else but a remarkable coincidence; and it is doubted, to this day, that the theory of gravitation has anything to do with it as a cause. It seems natural, however, to conclude that a constant effect must have a constant cause; and there are several considerations which are decidedly opposed to the idea of a mere fortuitous coincidence in time of these two revolutions.

That satellite of Saturn which revolves around its primary at a distance of nearly two millions five hundred and sixty thousand miles, only makes one complete turn upon its axis while revolving once in its vast orbit of fifteen and a half millions of miles. There is good reason for believing that all the four satellites of Jupiter rotate once on their axes while making one revolution about the planet. In fact there is a fair presumption that all the satellites are under the same law in regard to their movement of rotation. Are we to believe then, that in all these various examples, the orbits varying in magnitude, and the velocities in those orbits varying with the distance of the satellites from their primaries, the same fortuitous coincidence in time of the two revolutions exists?

We know that the planets have an original and independent motion of rotation, which was given to

them at the same time as their motion of translation; also, that there is no coincidence whatever, in time, of this motion of rotation and that of their revolution round the sun; and, after studying such examples of rotation, and the mode of operation of the laws by which it has been determined, we come naturally to associate an original motion of rotation, not with extreme slowness, but with rapidity. Euler was so struck by the resemblance of the spinning of a top, with the exact preservation of its vertical axis, and the rapid rotation of a planet, with the preservation of the direction of its axis, that, upon a series of observations of this nature, he founded his work "De motu turbinis." He observed that, so long as the top continued to spin rapidly, its axis was exactly vertical, but when, from friction of the point against the surface on which it spun, and from mutual gravitation of the material of the top and surrounding objects, the rapidity began to slacken, that the top began to reel, and the axis was lost. He saw then an exact purpose in the rapidity of rotation. The earth, the axis of which preserves its parallelism to itself all round its orbit, rotates so rapidly, that an object placed upon any point of the equator, moves at the rate of one thousand and forty-two miles an hour, but an object placed on the corresponding part of the moon, moves only at the rate of ten and a half miles an hour; and if placed in a similar position on the satellite of Saturn referred to, would rotate

probably not quite one mile an hour. A very different impression therefore is made upon the mind by the rotation of a satellite, and that of a planet; sufficient, indeed, to excite our suspicion that these bodies are acted upon by different impulses to those which determine the rotation of a planet, or by impulses differently communicated.

When a globular body rotates, its peripheral parts are moving more rapidly than the central, as the circumference of a wheel moves more rapidly than the parts which are close to the axle: as if, in fact, any part of the circumference would describe an orbit round a central point. It is doubtful if a satellite, with a slow independent movement, could maintain a rotary equilibrium in the presence of immense gravitating forces, which must necessarily impress it with some kind of motion in agreement with their own mode of action.

As the endeavour is now made to show that the moon has no original, or independent motion of rotation, but that such motion is impressed or forced upon her by the co-operation of certain great forces of nature, to which she is necessarily subject, it would, obviously, be impossible, even to commence such an enquiry, without laying on one side the theory of an original rotatory motion. We shall suspend this theory therefore pending the time the moon is thus put upon her trial; premising, however, that it shall be taken up again afterwards if found necessary.

It being certain that the moon's axis of rotation is dynamically stable, as well for a forced as for a self rotation, the endeavour will also be made to show— 1. By what mode of operation of the two great forces of motion and gravitation, the moon is made to rotate, and that in strict accordance with the Newtonian theory. 2. That such rotation, having been developed, it must necessarily have a very exact limit imposed upon it as to rapidity. 3. That only one complete rotation can possibly take place in one period, or revolution. 4. That the time occupied by the moon in making one complete turn on her axis must necessarily be the same as that of describing one complete revolution round the earth.

As determined by the theory of gravitation, when two masses of matter, or globes, being impelled or drawn by a force, are made to move in the neighbourhood of one another, their paths are deflected, the two globes tending to revolve around one another, or about a common centre of gravity. The earth and moon are two such spheres, but in consequence of the great predominance of the earth's mass and gravitating force, the moon is made to move in a concave path around it; and in this way is determined the moon's motion of perpetual continuance around the earth. In its great journey round the sun, therefore, of six hundred millions of miles, the earth may be described as carrying along with it the moon's orbit.

If a man carries any kind of vehicle, with a wheel under it, the wheel does not, of course, turn round, but if the man drops the wheel upon the ground, and then adds motion, the wheel immediately begins to rotate—and why? because sufficient cohesion is now established between the under surface of the wheel and the ground to cause a certain amount of resistance, or impediment, to the advance of the wheel at its lowest arc; the highest arc, suffering no such impediment, must yield first; beginning to descend and come forward in the direction of the motion, at the same time that the lowest arc is forced out of the impediment, and made to ascend in the opposite direction. Every part of the circumference of the wheel, coming, in turn, under the influence of the same obstacle, is made to overcome it in the same manner, and the wheel continues to rotate. The moon, by reason of an original impulse, might advance in her orbit without any rotation, for ever, for there is nothing in the motion of translation to make a globe rotate; but if there could be offered to that hemisphere which presents to the earth, a certain amount of resistance which does not affect the other hemisphere, then, aided by the motion which has been given, we might succeed in making her turn round while she advanced, as the wheel just now did. But how can this be done, the moon is separated from the earth by a considerable interval? This, however, is of no great consequence; gravitation will come to our aid here as in every part of this demonstration.

By the Newtonian theory it is shown that every particle of matter attracts every other particle, and that a mass, constituted of such particles, attracts any other mass so constituted with a force which is exactly in the ratio of the quantity of ponderable matter it contains. When two masses, however, attract one another, they do not attract merely as masses, but as collections of particles; the particles constituting their surfaces, as opposed to one another, will attract first, then those particles which are next within their surfaces; then those which are between these and the median plane of either sphere; as if, in short, any two globes so acting, would pull one another apart at the plane of junction of their two hemispheres.

When one hemisphere of the moon is opposed to one hemisphere of the earth, the particles composing the surface, and those next within the surface of the two hemispheres, are mutually attracting; and it is obvious that these two opposed hemispheres are placed under very different circumstances, as regards gravitation, to the other two, which present in the opposite direction.

The great proximity of the moon to the earth must now be carefully borne in mind, the moon being very much less than a quarter of a million of miles distant, while the nearest planet, Venus, is considerably more than twenty millions of miles from the earth.

The two spheres, then, being so near to one another, are now placed in such a relative position, that mutual

surface gravitation must act with great power; the particles composing the surface and those next within the surface of the moon's hemisphere, and the particles which are similarly placed in a very large part of that of the earth, mutually attracting. In this way is established exactly that amount of temporary cohesion of the two hemispheres which is necessary for our purpose; and it now becomes a simple problem in dynamics, that, when one globe moves over the surface of another, its lower hemisphere, or that which is opposed to the other globe, suffering an impediment to its free motion, the upper hemisphere having no such restraint imposed upon it, and the entire globe being impelled by a common motion, in a direction parallel to the surface of the globe over which it moves, its upper hemisphere must yield first; the highest arc descending, and coming forward in the direction of the motion, while the lowest arc is forced out of the impediment which restrains it, and made to ascend in the opposite direction. Every arc of the great circumference of rotation, coming under the influence of the impediment, and being forced out of it, the entire globe must be made to rotate; an equatorial band of the rotating globe representing the circumference of a wheel.

In this way then is the moon made to rotate by the co-operation of the two great forces of motion and gravitation; the kind of action described being fully recognized in astronomical science, as the physical

Fig. 1

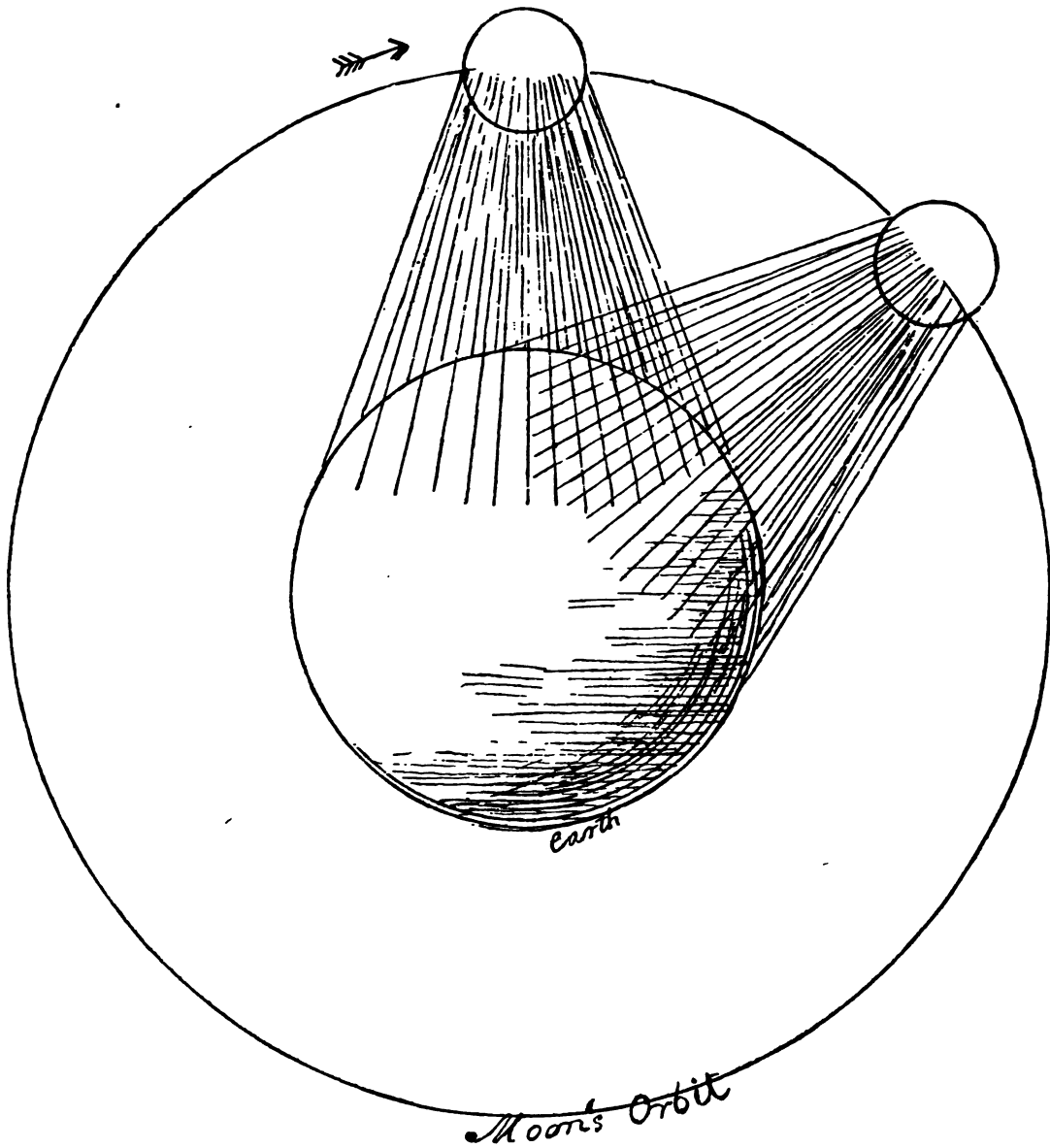

FIG. 1.

The moon is here represented revolving around the earth.

The lines, which connect the opposed hemispheres, represent mutual surface gravitation. It will be observed that the area of the earth's hemisphere which is presented to the moon, greatly exceeds that of the moon which is presented to the earth. In surface gravitation therefore, as well as in mutual mass gravitation, the earth's power greatly exceeds that of the moon. A swift motion having been given to the moon, while its lower hemisphere is restrained in the manner indicated, the highest arc of the upper, or unimpeded hemisphere, must descend, and come forward in the direction of the motion, and rotation become established.

The proportion of one globe to the other is the same as in nature.

cause of the precession of the equinoxes, and nutation. Precession may be described as a very slow, but continual, "retrogradation of the node of the earth's "equator on the ecliptic," the equinox travelling backward along the ecliptic in a direction from east to west; the cause being, the united action of the sun and moon on the surface, and parts next within the surface, of the great hoop or bulging out of the earth's equator, the matter of which, being inseparably identified with the earth's mass, the entire earth must yield to the movement by which this part is affected, and incline accordingly.

By far the greater part of this motion is due to the moon; for although her mass is very minute compared with that of the sum, she is nearer to the earth than the sun is by nearly four hundred times. The cause of nutation is exactly similar; but the whole of this motion is due to the moon. The associated action then of the two great forces of motion and gravitation, as pointed out by Newton, is the physical cause of precession, the motion here being that of the earth's rotation on its axis.

The moon, then, having been forced to rotate as she advances in her orbit, the question naturally arises—at what rate shall she rotate, as indicated by the movement of any small arc of her equator in a given time? or why should she not make several, or an indefinite number of rotations, while once describing her orbit?

Fig. 2.

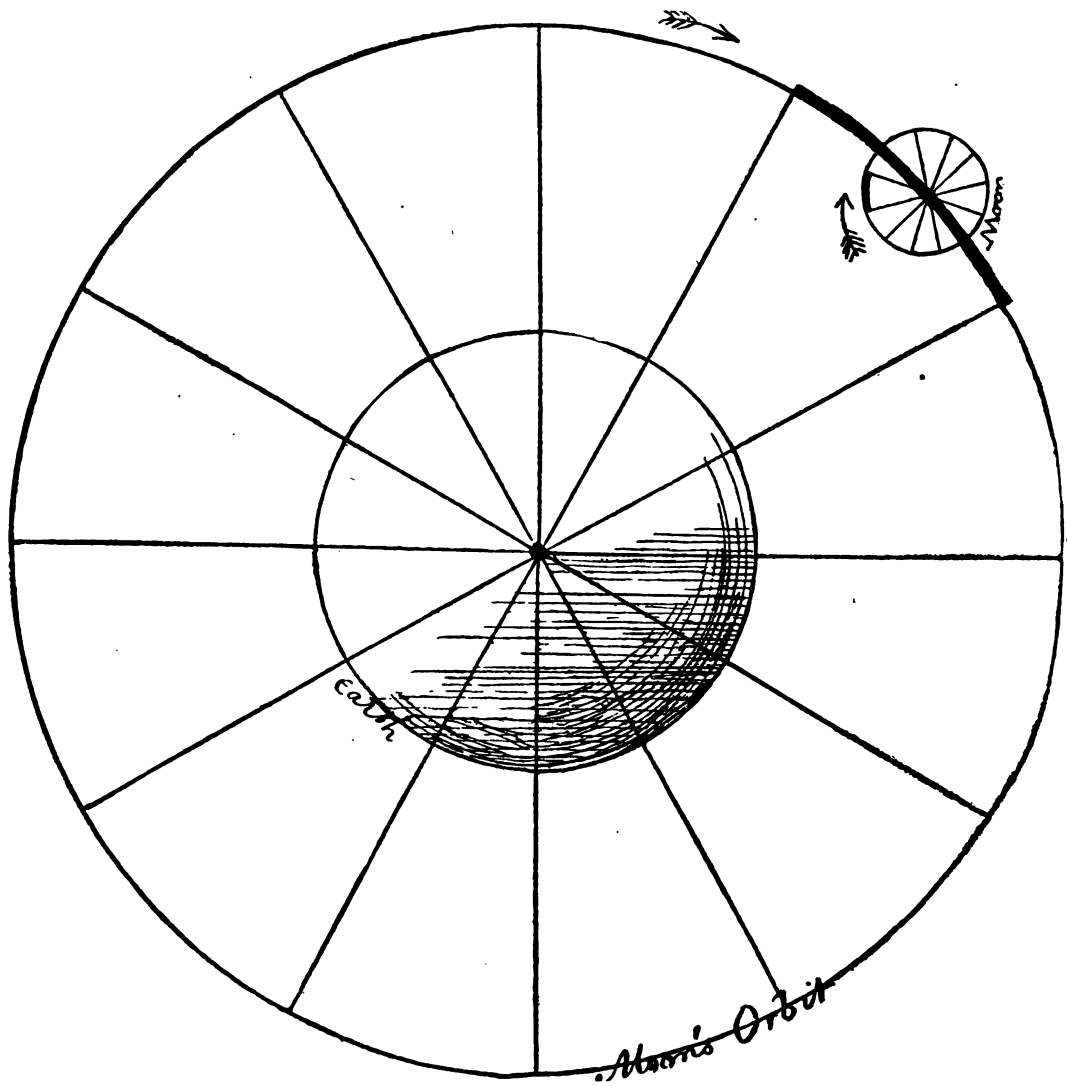

FIG. 2.

The moon is here seen revolving around the earth in the direction of the arrow; and at the same time rotating on her axis; a large arc of the revolution being described in the same time as a small one of the moon's equator, as indicated by the dark lines. Twelve arcs of each are represented; the disproportion of the arcs of rotation and revolution being much greater in nature than in the illustration. The two spheres bear the same proportion to one another as in nature.

shortly to be demonstrated, it follows that the two velocities cannot possibly co-exist in any other ratio than that indicated.

Here it is necessary to bear in mind the earth's relative magnitude as well as mass, which is very important, as extending more widely the area over which the gravitating influence extends. The earth's circumference is 25,000 miles, that of the moon only 6788 miles; the earth therefore overlaps the moon, and may be described as holding her in its grasp. It must be borne in mind, also, that we have to deal with globular bodies and a circular path.

It now has to be shown that the two revolutions, viz., the greater revolution of the moon in her orbit, and the lesser revolution of the moon's circumference, are necessarily accomplished in exactly the same time; the time being determined by the velocity of the moon's motion of translation. It must be remembered that the moon's rotation, as a forced motion, is not caused in one part of the orbit only, but that it is developed in every part of it, and at every instant, as the moon moves round.

By reference to the figure (3) it will be seen that a globular body is moving in a circular path. The black spot on the top indicates the situation of its axis of rotation. If the globular body moved round the circle without rotating, the black line would present to A in every part of it; but if the globe rotated once in

moving round the circle, the black line would present to A B C D and to A again in succession. It will now be observed that the globe has made one complete turn on its axis of rotation.

But within this circle is a great mass of matter, the mass predominating over the mass of the globular body in the ratio of 75 to 1.

It has been stated that the globular body, in moving round once, makes one complete rotation. It will now be seen that it cannot possibly make more than one. The straight lines, which in the figure connect the globe with the central mass, represent the mutual gravitation of the two masses; and it will be observed that these lines extend to the full diameter, as well as beyond, of the small globe. Supposing now that any force should so act upon the globe as to give it a tendency to make a second rotation before it has moved round the circle, then it will be at once seen that it cannot even commence the movement necessary for making such turn; for the force represented by the straight lines so holds it, that any attempt to turn in the direction of either dotted line must be instantly checked.

In figure 4 the restraint is shown in a mechanical manner; neither end of the cap can rise into the dotted half circle, while firmly held by the two cords. The rotatory movement, then, is so restrained by the great forces under which it is developed, that a new turn

Fig 3

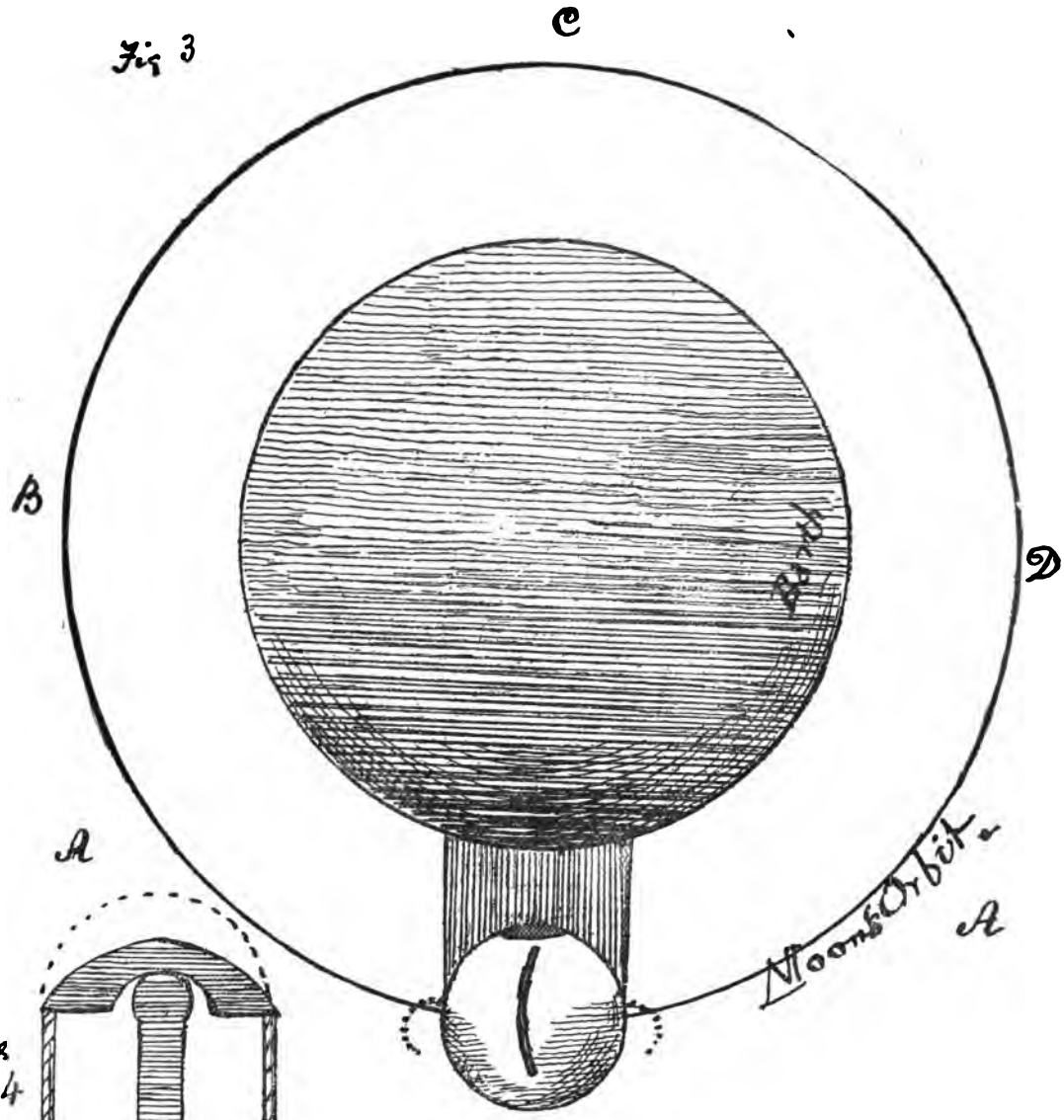

Fig 4

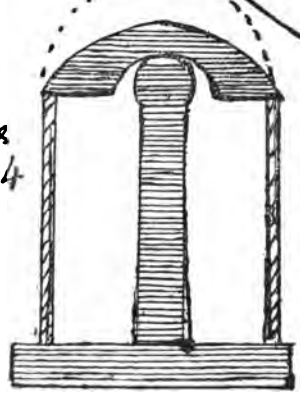

FIG. 3.

The straight lines which connect the globular body with the central mass, and which represent the gravitating force of both masses, are to be considered as moving round the entire circle as the globe itself moves round it.

FIG. 4.

A central support bears a moveable cap. So long as the cords on each side are held firmly and equally, neither end of the cap can move in the direction of the dotted half circle. This represents the manner in which the globular body is held by the gravitating force to its full diameter, neither end of which can possibly begin the movement necessary for making a new turn while describing a circle, and impressed throughout with a compulsory movement of rotation.

is not permitted even to be begun, during the time occupied in completing the circle, which represents one orbitual revolution.

Let a billiard ball be marked in the same way as the globular body; and then, being held between the thumb and finger, let it be moved slowly round the circumference of a common plate, and, during its progress, let it be turned once round upon an axis which is vertical to the surface of the plate. The circle and one rotation, are, of course, completed at the same time. Again, let the circle be begun, and, this time, let it be supposed that the plate represents a powerful force, which so acts upon the ball, that neither end of its diameter, which is held between the thumb and finger, can be made to begin the turn necessary for a second rotation in any part of the circle; which is therefore completed with only one rotation of the ball.

The lines which connect the small globe with the central mass are, in the plan, represented in one part only of the circle, but, as the globe moves round, they are equally applicable to every part of it.

The globular body represents the moon, the circle in which it moves, her orbit, and the central mass, the earth; and from the nature of the movement which has been described, it will be evident:—

1. That the moon cannot make one complete rotation on her axis until she has described one revolution in her orbit.

2. That a second turn upon her axis cannot possibly be made, or even begun, while moving once round in her orbit.

3. That, as there can be no pause in either the motion of revolution or in that of rotation, there must necessarily be an exact coincidence of the time in which both motions are accomplished.

The time, therefore, occupied by the moon in making one complete revolution in her orbit is necessarily the same as that occupied by her in making one complete turn upon her axis.

This inquiry could not, of course, have been carried on with the theory of an original and independent motion of rotation; but it was premised that such theory might be taken up again if found necessary. The question now is, ought it to be resumed? It is certain that a body may be projected, as well without, as with, a rotatory motion; and the inquiry has been conducted on the presumption that, when the moon's original motion of translation was given to her, the motion of rotation was not also given, but was left to be impressed or forced upon her.

It is quite clear that it was in the design that the satellites should rotate very slowly, and if the method of impressed rotation which has been described, suffices to make them turn round with exactly that rapidity which the Creator wished, why should not this plan have been adopted as well as any other? It would be

difficult to find a single argument against it. The invention of the Creator has no limit, and He adopts that method which He thinks the best. Certainly we cannot look for any support to the theory of an original motion of rotation, in the study of the forces in operation, and the laws by which those forces are regulated, in rapidly rotating planets, with an exact preservation of their axes; and although, in both cases, there is rotation on an axis, this motion is, dynamically, of a very different nature in a forced or impressed rotation, and in that which is made to accompany an original motion of translation. It can be demonstrated also, that the moon cannot move so near the earth without the mutual surface gravitation of the two opposed hemispheres of the earth and moon being called into activity; and this result cannot happen without a rotatory motion being given to the moón; if, then, the moon had an original motion of rotation also, there would be two causes in operation, at the same time, to effect the same purpose!

There is little doubt now that all the satellites are under the same law as regards their axical rotation; that each makes one complete turn on an axis, and only one, while making one orbitual revolution; it matters not what may be the magnitude of the orbits, or the velocity in those orbits. The illustration already given of the moon's motion in her orbit around the earth, will apply to all.

Recapitulation.—1. The weight of argument is opposed to the theory of an original and independent rotatory motion of the moon and other satellites. It is right therefore, that, in the cause of science, an effort should be made to ascertain what the method really is which the Creator has adopted, to ensure the slow and remarkable movement which we find to exist throughout the satellite system.

2. An original motion of translation is not necessarily accompanied by a rotatary movement, but such original motion forms an essential part of the cause of rotation.

3. There is no argument to be derived from the known co-operation of the two great forces of motion and gravitation, which can be adduced against the method of an impressed or forced rotation; on the other hand, it obtains direct support from the mode of combined action of the causes of precession.

4. The moon's mean distance from the earth and sun being fixed and determinate, her axis must be dynamically stable, equally for an impressed, as for an original and independent rotation.

5. The moon being so near to the earth that the mutual surface gravitation of the two hemispheres of the earth and moon which are, at any time, opposed to one another, must be called into very powerful operation, cannot advance in her orbit without rotating. The essential conditions of such rotatory movement, viz., motion and surface gravitation, being always

present, and necessarily operating as causes, the effect must follow.

6. Those forces then, being in constant operation, which must cause a movement of rotation, it would be absurd to suppose that any other cause of such motion had been set in operation.

7. This rotatory movement is not generated in one part of the orbit, to be continued in the rest, but is developed at every instant of the moon's progress in her orbit, and that with great and irresistible force.

8. The rapidity of the movement of rotation, on the very moment of its development, has very exact limits imposed upon it by the force of the mutual mass gravitation of the two spheres, by which it is restrained to one rotation while the moon makes one revolution round the earth.

OXFORD,
April, 1885.